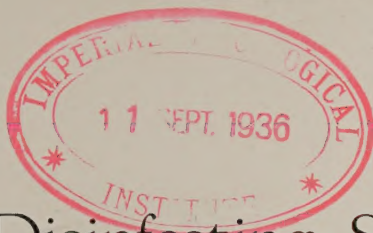


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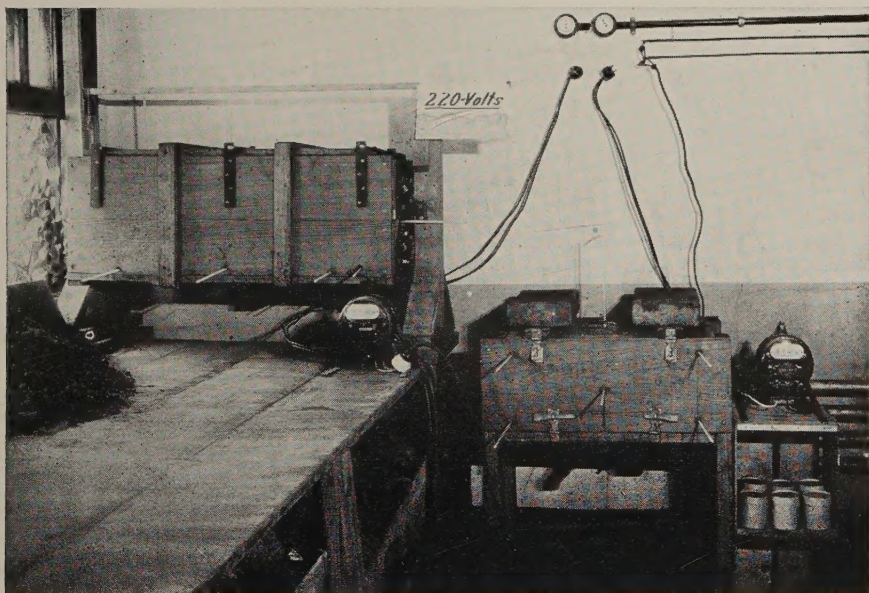
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Disinfesting Soils by Electric Pasteurization

A. G. Newhall and M. W. Nixon



INDIRECT-HEATING TYPE OF SOIL PASTEURIZER COMPARED WITH THE DIRECT-HEATING TYPE

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DISINFESTING SOILS BY ELECTRIC PASTEURIZATION¹

A. G. NEWHALL AND M. W. NIXON²

Heat is considered by many authorities to be the most effective and least objectionable disinfestant for the destruction of pathogenic fungi, bacteria, nematodes, weed seeds, and insect pests in soils. However, steam and even abundant hot water are not available to many growers. In view of its increasing availability and of its economy in some localities, a study of electricity as a source of heat and an intensive study of two general types of portable electric soil pasteurizers have been undertaken by the Departments of Plant Pathology and Agricultural Engineering of Cornell University, in cooperation with the engineering service of the Empire State Gas and Electric Association. Preliminary discussions of this have been published by the senior author (Newhall, 1935 a, b.).

MATERIALS

One type of equipment employed the direct-heating principle, said by Scott (1932) to have been originated by Charles W. Wildebour.³ The electric current is passed directly through the soil by means of properly spaced electrodes consisting of metal plates, or fins. The soil is heated by the resistance it offers to the passage of the current. Krewatch and Kable (1933) pointed out the difficulties involved with vertical electrodes. Therefore a box with only two electrodes placed horizontally was devised by the Department of Agricultural Engineering of Ohio State University (Blauser, 1934, and McCuen and Blauser, 1934) and called the *Ohio type soil sterilizer*. This type was used in the work reported here, with slight modification (figure 1). Essentially this pasteurizer consists of a stout cypress box of variable dimensions; the one used at Cornell University had inside measurements of 24 by 18 inches and was 10 inches deep with a removable lid and a trap-door bottom to facilitate filling and emptying, and legs to support the box at a convenient height from the floor. The top and bottom were lined with 20-gauge galvanized sheet iron. These linings serve as the two electrodes and are connected to a 230-volt

¹ This is one of several agricultural-research projects undertaken with funds supplied by the electric power companies serving the rural territories of the State. The term *disinfest* is used here in its broadest concept, as set forth by Whetzel and McCallan (1930), to include the destruction of all kinds of deleterious organisms by any means. Pasteurization is considered but one means of disinfesting a soil. Steaming, drying, and the use of chemicals are other common methods. Although by definition and common usage *pasteurizing* refers to the destruction of harmful microorganisms in fluids by low-temperature treatment (56–70°C, or 131–158°F.), nevertheless it is believed entirely permissible to enlarge its concept to include treatment of soils or other solids for the destruction of nematodes, insects, and weed seeds, in addition to fungi and bacteria. Indeed it has already been employed in this sense in the far west where dried fruits are being *pasteurized* on a large scale (Fellers, 1930).

It is well known that the term *sterilization* is not strictly correct as applied to the ordinary heat treatment of soils because some spore-forming organisms usually survive. The term becomes even less applicable where comparatively low, or pasteurizing, temperatures are employed. *Partial sterilization* is a more nearly accurate term, although cumbersome and ambiguous and possibly suggesting failure to attain the goal. Similarly, *disinfection* is not strictly applicable to the treatment of an inanimate substance like soil although very commonly used. Only living bodies can become infected because infection is a morbid process, or interaction between living organisms. Inanimate substances become infested, or contaminated.

² Assistant research professor of Plant Pathology in the New York State College of Agriculture, and Rural Service Engineer of the Empire State Gas and Electric Association, respectively.

³ Viscount Elveden (1921) seems to have been the first to report successful results from heating soils by the application of an alternating current. Unfortunately no description of the method was given.

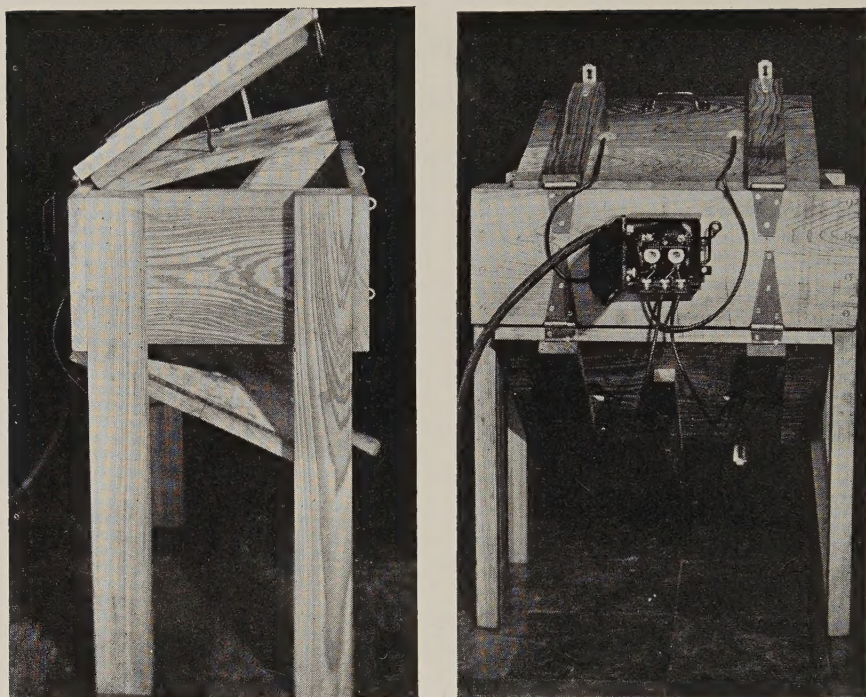


FIGURE 1. A DIRECT-HEATING, OHIO TYPE, SOIL PASTEURIZER, WITH A CAPACITY OF 2.4 CUBIC FEET

This has a variable-current demand sometimes exceeding 5 kilowatts, and requires from 25 minutes to six hours to treat a charge of soil, depending upon the kind and condition of the soil, with respect to soluble salt and moisture content.

alternating-current supply when the pasteurizer is in operation. In figure 1 the Ohio type is shown in side view on the left with the upper electrode loosened and dropped down from the lid a few inches, and on the right a rear view is presented to show the switch box, fuses, and electrical wiring. In figure 2 is shown one made from a stout oak half-barrel to eliminate the four corners. Both of these require a rather heavy service line because they draw more than 5 kilowatts of electricity, some times when loaded with rich soil.

The other soil pasteurizer, referred to hereafter as the *New York type*, employed the indirect-heating-element principle (figure 3). It was originated and developed by the joint work of D. E. Blandy, L. B. Carney, and the junior author, in 1931, and was described the following year by Carney (1932). It consists of a stout cypress box of variable dimensions, provided with pipe-type space heaters, placed at suitable intervals to impart their heat by thermal conductance to the surrounding soil. The heaters were of $\frac{3}{4}$ -inch galvanized-iron pipe possessing a heat flux in one box of 2.12, and in another of 2.45, watts per square inch of heater surface, or approximately 100 watts to the linear foot.⁴ They were spaced in one

⁴Heaters manufactured by the Hynes and Cox Electric Corp., Albany, New York.

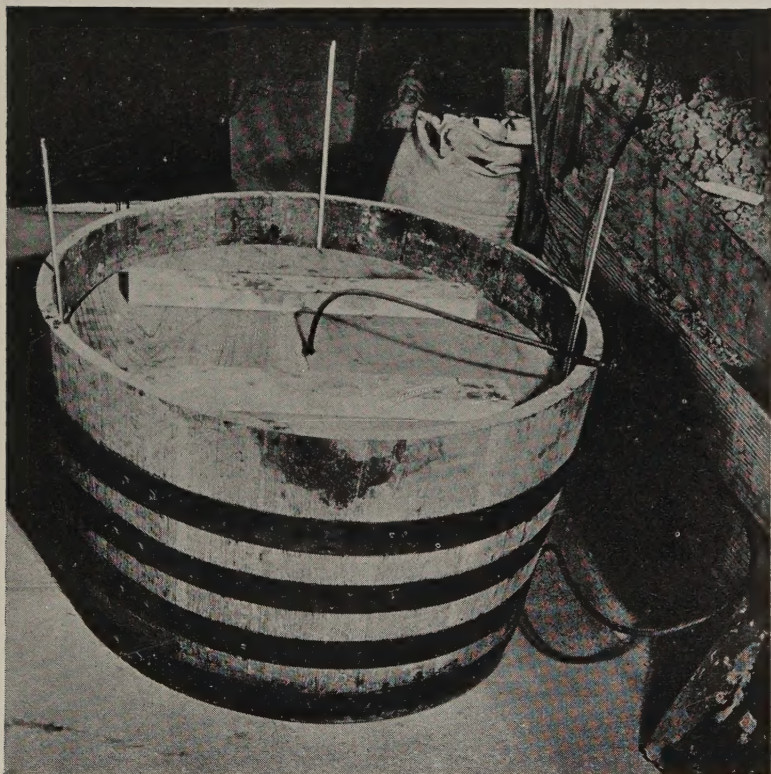


FIGURE 2. A SIMPLIFIED DIRECT-HEATING TYPE OF PASTEURIZER IN WHICH THE CORNERS HAVE BEEN ELIMINATED

To safeguard the operator and livestock some kind of waterproof insulation should be provided around the outside of such a container

box 6, and in another, 8 inches apart, on centers, giving a ratio of 345 and 237 watts respectively per cubic foot of soil. Legs and a trap-door bottom to facilitate emptying were later provided.

METHODS

The aim of this investigation was twofold. The first was to determine, under commercial conditions, the disinfesting ability of these pasteurizers with respect to several common plant pathogens, using temperatures well below boiling. This aim was accomplished in two ways: (1) by planting pure cultures of several common soil-inhabiting pathogens in various parts of the soil mass, and recovering and testing these organisms for viability after a certain heating period; (2) collecting good-sized samples of soil from a number of commercial greenhouses in the State, where damping-off is prevalent, sterilizing a portion of the sample, and growing seedlings in the treated and untreated portions.

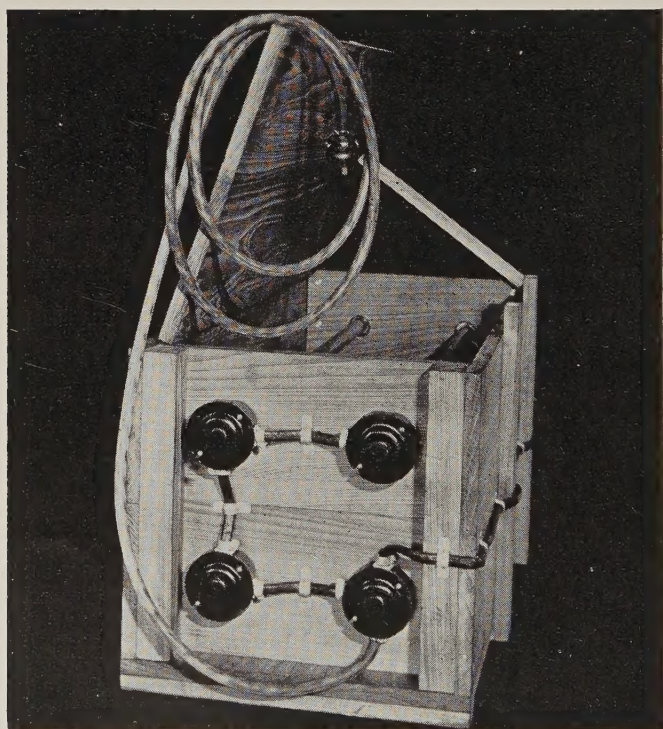
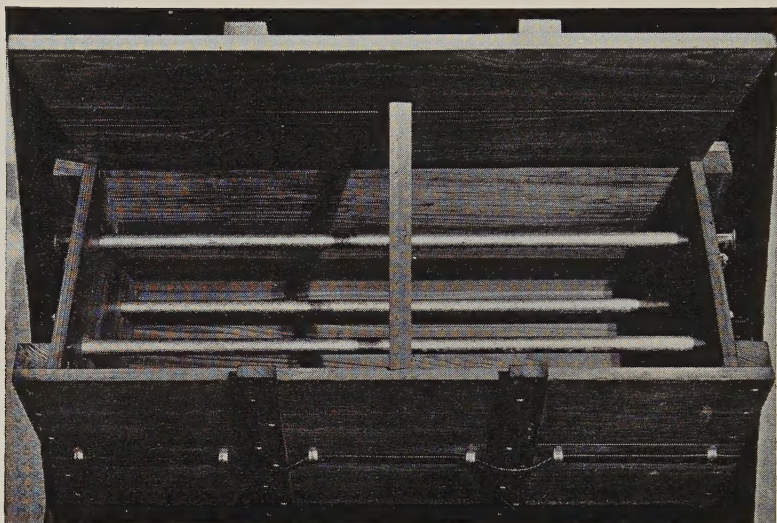


FIGURE 3. AN INDIRECT-HEATING, NEW YORK TYPE, SOIL PASTEURIZER
WITH A CAPACITY OF 5 CUBIC FEET

This has a constant-current demand of 1600 watts, and requires from 4 to 5 hours to treat a charge of soil (4 bushels). A trap-door bottom can be provided to facilitate emptying

The second aim was to determine and compare the cost of operation of these two types. This was accomplished by metering the current consumed and reducing the data to kilowatt hours per cubic foot of soil per degree centigrade rise in temperature. The energy consumption for a 50°C. rise, i.e. from initial 20° to final 70°C. was then computed, which figure approximated that which would be expected in actual usage.⁵

STUDY OF THERMAL DEATH POINTS

One of the first things to be decided was the soil temperature at which the electric current should be cut off. According to Elliott (1930), there are 102 bacterial pathogens for which thermal death points have been recorded, and of these only four lie above 59°C. and none are above 69°C. Thom and Ayers (1916) have shown that the conidia of many fungi also are destroyed by heating for 30 minutes at 62.8°C. A list of 16 common pathogens, given in table 1, shows that it is the exception rather than the rule for fungus protoplasm to withstand a temperature as high as 65°C. for even a few minutes under moist conditions. Since insect life is also

TABLE 1. THERMAL DEATH POINTS OF A NUMBER OF PLANT PATHOGENS

Pathogen	Form	Tem- perature	Time	Authority
		Degrees centi- grade	Min- utes	
<i>Actinomyces scabies</i>	Conidia.....	54	10	Lutman and Cunningham (1914)
<i>Alternaria solani</i>	Conidia.....	45	...	Rands (1917)
<i>Botrytis cinerea</i>	Conidia.....	50	10	Smith (1923)
<i>Cercospora apii</i>	Mycelium.....	52	10	Klotz (1923)
	Conidia.....	51	10	Klotz (1923)
<i>Colletotrichum lindemuthianum</i> ...	Mycelium.....	50-52	10	Muncie (1917)
	Spores.....	46-48	10	
<i>Corticium vagum</i>	Mycelium.....	50	...	Merrill (acc. Hartley, 1921:28)
	Sclerotia.....	60	...	Merrill (acc. Hartley, 1921:28)
<i>Fusarium moniliforme</i>	Conidia.....	70	10	
<i>Helminthosporium sativum</i>	Mycelium and spores.....	54	10	Christensen (1926)
<i>Heterodera marioni</i>	All stages.....	48	10	Newhall (1930)
<i>Mucor species*</i>	Conidia.....	57	30	Thom and Ayers (1916)
<i>Penicillium species†</i>	Conidia.....	60	30	Thom and Ayers (1916)
<i>Phoma apiicola</i>	Spores.....	49	10	Bennett (1921)
<i>Pythium debaryanum</i>	Spores and mycelium...	65	10	Merrill (acc. Hartley, 1921:28)
<i>Rhizopus nigricans</i>	Spores.....	54.5	30	Thom and Ayers (1916)
<i>Sclerotinia sclerotiorum</i>	Sclerotia.....	48-50	5	Joshi (1924)
<i>Septoria lycopersici</i>	Spores.....	52	10	Levin (1916)

* Four species with thermal death points below 57°C.

† Twenty-three species with thermal death points below 60°C.

known to be unable to withstand such temperatures, and the thermal death points of many of the most common plant viruses also lie in this range⁶, and since most weed seeds are believed to be killed below these temperatures, the authors arbitrarily chose 70°C. as the minimum soil temperature at which the current would be turned off. The temperature was determined by 5 or 6 thermometers inserted through holes in various parts of the pas-

⁵Centigrade temperatures are used throughout this bulletin, but a centigrade-Fahrenheit temperature conversion scale is given on the back cover (figure 9).

⁶Exceptions are some which occur in tobacco and tomato.

teurizers, and at the end of each test run at least 25 additional temperature readings were taken through the soil mass as quickly as possible.

Having chosen, on the basis of the above data, 70°C. as a safe end-point temperature, this conclusion was checked by a series of tests in which pure cultures of several common pathogens, representing different major groups, were planted in the soil and, after treatment, were recovered and tested for their viability. Carrots were inoculated with *Erwinia carotovora*, representing the bacteria, and, after incubation for a few days, pieces of the rotting carrot were placed in small cheesecloth bags and buried in different parts of the soil mass in one of the pasteurizers. Similarly, ten sclerotia of *Sclerotinia sclerotiorum*, representing this group of fungi, were planted in different places. For the nematodes, pieces of freshly dug cucumber roots, showing large galls due to *Heterodera marioni*, were employed. Rhizoctonia, Fusarium, and Phytophthora were grown on steam-sterilized wheat kernels and a dozen of these kernels were placed in each of several cheesecloth bags. By planting the bags in different places in the soil mass where slightly different final temperatures were reached, it was possible to obtain a record of survival at several temperatures. The results of these tests have been summarized in table 2 where it may be observed in the last column that none of the organisms tested were able to survive final temperatures above 68°C. It is not implied that these lethal temperatures represent true thermal death points. In the first place, the temperature was not constant in any of these tests, because the figures given were but end points in a process of gradual temperature elevation; and in the second place, if smaller temperature intervals had been recorded, many or all of these end points might have been different. The time factor and soil moisture must also be considered since they were neither standardized nor invariable.

TABLE 2. SOME LETHAL TEMPERATURE CONDITIONS FOR SEVERAL PATHOGENS IN SOIL HEATED IN AN ELECTRIC PASTEURIZER

Pathogen *	Source	Soil and moisture	Period of heating †	Highest survival temperature recorded	Lowest lethal temperature recorded
		Per cent	Minutes	Degrees centigrade	Degrees centigrade
Rhizoctonia.....	Potato.....	Muck, 134..	45	54°	65°
Rhizoctonia.....	Bean.....	Muck, 134..	40	65°	68°
Rhizoctonia.....	Tomato.....	Muck, 139..	50		67°
Rhizoctonia.....	Lettuce.....	Muck, 123..	55	50°	68°
Sclerotinia.....	Bean.....	Muck, 108..	75	63°	70°
Sclerotinia.....	Bean.....	Muck, 123..	50	50°	58°
Sclerotinia.....	Bean.....	Muck, 5....	210		56°
Sclerotinia.....	Bean.....	Muck, 0....	210		60°
<i>Erwinia carotovora</i>	Celery.....	Muck, 129..	210	66°	
<i>Erwinia carotovora</i>	Celery.....	Muck, 108..	70	63°	70°
<i>Erwinia carotovora</i>	Celery.....	Loam, 23... Muck, 139..	215 90		68° 72°
<i>Fusarium</i> sp.....	Celery.....	Muck, 139..	50	62°	66°
<i>Fusarium</i> sp.....	Celery.....	Muck, 123..	50	58°	68°
<i>Phytophthora cactorum</i>	Apple.....	Muck, 127..	50	55°	68°
<i>Heterodera marioni</i>	Cucumber..	Muck, 123..	50	47°	55°

* *Pythium ultimum* was controlled in several other experiments in which the temperature did not exceed 70°C.

† Periods of 90 minutes or less indicate that the Ohio-type pasteurizer was employed; all periods longer than this indicate the New York type.

COMPARISON OF ELECTRIC, FORMALDEHYDE, AND STEAM METHODS

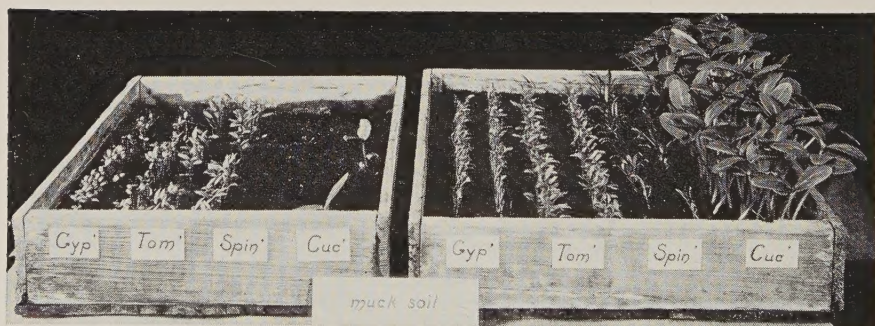
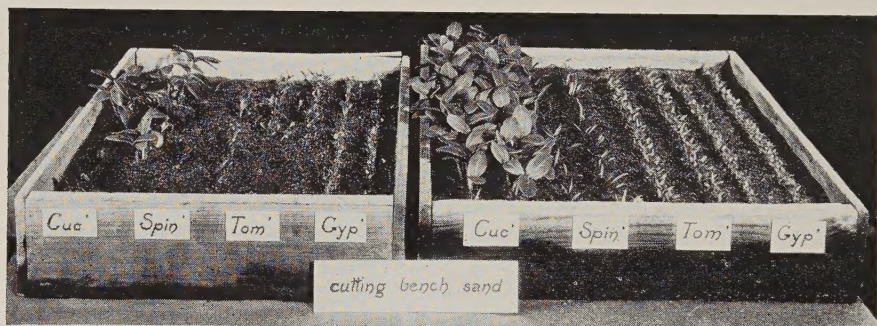
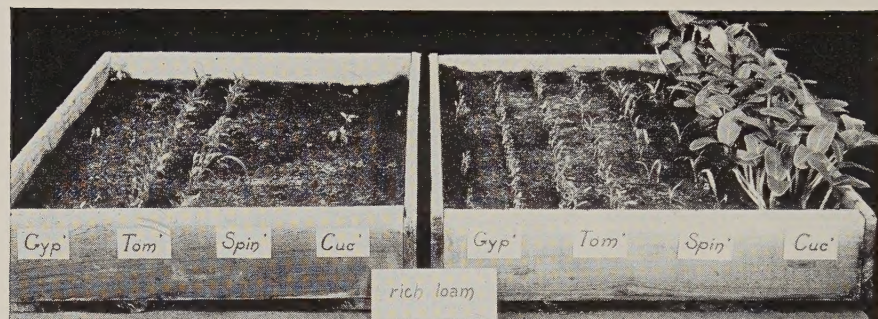
As an additional check on the effectiveness of this comparatively low-temperature electrical method of heat treatment, in comparison with other recognized methods of controlling damping-off, a quantity of sandy loam soil from a commercial greenhouse, where damping-off was prevalent, was divided into four parts, one of which was electrically heated to 70°C. as before, one autoclaved at 15 pounds steam pressure for one and one-half hours, and one treated with liquid formaldehyde after the manner described by Guterma and Massey (1935), i.e., 1 ounce of 40 per cent commercial formalin thoroughly mixed with 1 cubic foot of soil. The day after treatment the seeds of four vegetables and three ornamentals were sown in these four lots of soil. Examination of table 3, where the data on emergence of the seedlings are summarized, shows that considerable pre-emergence damping-off took place in the checks in all but the celery and tomato rows. The treated flats, on the whole, were all vastly better than the check.

TABLE 3. COMPARISON BETWEEN STEAMED, ELECTRICALLY PASTEURIZED AND FORMALDEHYDE-TREATED RICH SANDY LOAM ON CONTROL OF DAMPING-OFF (*PYTHIUM* AND *RHIZOCTONIA*) AS MEASURED BY THE PERCENTAGE STANDS OF SEEDLINGS 10 TO 20 DAYS AFTER SOWING

	Steamed	Electrically pasteurized	Formaldehyde	Check
	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
Cucumber.....	92	90	96	0
Sweet pea.....	86	82	88	14
Marigold.....	86	90	94	44
Spinach.....	66	75	72	2
Tomato.....	56	58	26	54
Gypsophila.....	54	65	42	24
Celery.....	45	70	12	70

In a further test of the relative effectiveness of electric pasteurization, in comparison with several standard soil treatments and seed treatments for the control of damping-off, electric pasteurization was again found to be as reliable as any of the treatments. The data are presented in table 4. In this and in other tests not reported here, soil treatments were uniformly superior to seed treatments, with the exception of the Semesan soil-drench method, which sometimes proved very harmful. Therefore, soil treatments are preferable wherever possible, as in indoor preparation of seedling flats, potting soil, cold frames, and seed beds. Out of doors where soil treatment on a field scale is scarcely feasible, one of the seed treatments, as with cuprous oxide, zinc oxide, organic mercury, or copper carbonate, is the most logical substitute because of the greater economy.

As a still further check on the effectiveness of these pasteurizers under more nearly commercial conditions, a number of samples of different kinds of soil were collected from places in the State where damping-off was troublesome to the grower. These samples included cutting-bench sand, sandy loam top soil, rich compost, and muck. The Ohio pasteurizer was used to treat all samples. An examination of figure 4 shows that the method



DAMPING-OFF CONTROL

FIGURE 4. RESULTS OF TREATING 3 KINDS OF SOIL IN AN ELECTRIC PASTEURIZER, AS MEASURED BY THE NUMBER OF HEALTHY SEEDLINGS OF CUCUMBER, SPINACH, TOMATO, AND GYPSOPHILA WHICH EMERGED; TREATED SOILS ON THE RIGHT

The same number of seeds were sown in the untreated and the treated soils.

TABLE 4. COMPARISON OF SOME STANDARD SOIL AND SEED TREATMENTS FOR DAMPING-OFF CONTROL, AS MEASURED BY THE ACTUAL STANDS OF SEEDLINGS 21 DAYS AFTER SOWING IN SANDY LOAM (*PYTHIUM* AND *RHIZOCTONIA*)

Treatment of soil or seed	Number of seedlings up in 3 weeks *					
	Cucumber	Spinach	Beets	Tomato	Carrot	Total
1. Electrically pasteurized (sown next day)...	47	87	41	82	31	288
2. Formaldehyde liquid, 1 ounce per cubic foot (sown next day).....	42	82	48	76	27	275
3. Formaldehyde dust 3 ounces per cubic foot (sown next day)†.....	47	83	52	73	20	275
4. Steam "sterilized" 1½ hours (sown next day).....	45	72	51	75	27	270
5. Formaldehyde liquid, ½ ounce per cubic foot, (sown same day).....	42	80	62	73	12	269
6. Seed coated, zinc oxide (Vasco 4).....	45	60	30	77	21	233
7. Seed coated, red copper oxide+zinc oxide on soil.....	33	64	44	69	14	224
8. Seed coated red copper oxide.....	36	31	39	69	17	192
9. Check, no treatments.....	8	26	39	7	0	80
10. Semesan soil drench, 0.3 per cent solution at 2 quarts per square yard (after sowing seed).....	5	4	17	28	4	58

* Fifty seeds of each kind were sown in each treatment, except tomato and spinach, of which 100 were sown, making a possible total of 350 in each flat.

† Trioxo KD345 at slightly less than the rate recommended by manufacturer.

was equally successful in eliminating damping-off from these widely differing kinds of soil. In all instances the fungi involved seemed to be chiefly *Pythium* sp. and *Rhizoctonia* sp.

COST OF OPERATION

Having decided that both types of electric pasteurizers are capable of effectively controlling many of our worst soil-borne pathogens, attention was turned to the amount of current consumed, since this is the major item of expense. The data from 81 test runs have been summarized in table 5, where the kilowatt hours per cubic foot per 50-degree-centigrade rise in temperature are given.

TABLE 5. SUMMARY OF TEST DATA ON ELECTRICITY CONSUMPTION WITH SAND, SANDY LOAM, AND MUCK, IN TWO TYPES OF PASTEURIZERS

Kind of soil	Tests	Mean soil moisture	Mean temperature rise	Mean watt hours per degree rise per cubic foot	Mean kilowatt hours per 50-degree rise per cubic foot (± S. E.)*
New York pasteurizer (indirect heating)					
	Number	Per cent	Degrees centigrade	Hours	Hours
Sand.....	10	5	55	23	1.17±0.08
Fine sandy loam.....	8	16	50	24	1.23±0.05
Muck.....	4	136	47	28	1.37±0.12
Ohio pasteurizer (direct heating)					
Sand.....	7	6	46	22	1.08±0.09
Fine sandy loam.....	39	17	54	22	1.12±0.03
Muck.....	13	123	49	27	1.33±0.04

* The standard errors of the means are given as an indication of their variability and hence of their reliability as representatives of the true mean. For example, 1.17±0.08 indicates that in further trials under the same conditions results could be expected to fall two-thirds of the time between the limits of 1.25 and 1.09 kilowatt hours.

Muck soil with its much higher moisture content required a little more current than did the mineral soil. This difference is more or less significant. From a consideration of the standard errors it can be shown mathematically that there is no significant difference between the performance of the two types of pasteurizer, although at first glance the Ohio type appears to be a little more economical.

In general, a cubic foot of soil can be treated effectively with the expenditure of from 1 to 1.3 kilowatt hours of electricity. In actual practice, when only damping-off fungi are present, growers are cutting off the current at 60°C., or even lower and leaving the soil undisturbed over night, this disinfecting with less than 1 kilowatt hour per cubic foot. At 3 cents a kilowatt hour, since a cubic foot will fill from two to four ordinary-sized flats, it would cost approximately 1 cent a flat. The writers' conclusions in this regard are similar to those of several others (Anonymous, 1935) (Blauser, 1934) (Carney, 1932) (Hervey, 1934) (Horsfall, 1935) (Krewatch and Kable, 1933) (McCuen and Blauser, 1934).

IMPORTANCE OF PROPER MOISTURE AND OTHER FACTORS

A certain minimum initial soil moisture was found to be essential for the most satisfactory operation of both types of pasteurizer, although the reasons for this are not the same in the two instances. In the New York type it is needed for thermal conductivity. Without a sufficient moisture supply, premature drying and hence excessive overheating would take place close to the heating units. This has a somewhat detrimental effect on soils of high organic content similar to, if not identical with, the effect often experienced with soil steamed under pressure. This was demonstrated

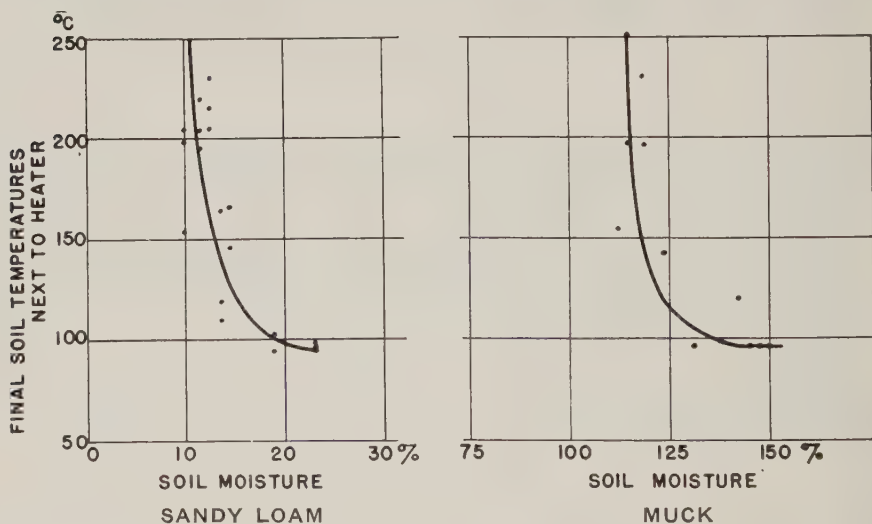


FIGURE 5. RELATION BETWEEN INITIAL SOIL MOISTURE AND FINAL TEMPERATURE ADJACENT TO HEATING UNITS AT END OF HEATING PERIOD, IN THE NEW YORK (INDIRECT-HEATING) TYPE OF PASTEURIZER

Soil temperatures, taken at about 30 places in the soil mass, at the end of each run, ranged between 70 and 80°C.; temperatures close to heaters are indicated by the dots

several times by growing tomato and other seedlings in overheated muck collected from the immediate vicinity of the heating units. A fine sandy loam with a total water-holding capacity of 49 per cent (Hilgard 1-centimeter column method) (Hilgard, 1912) was found to require at least 17 per cent moisture on the dry-weight basis if the entire mass was to be heated to 70°C. before overheating took place around the units. Similarly, muck soil required at least 130 per cent. This relation between initial soil moisture and final temperature close to the heaters at the time the entire mass reaches 70° is graphically presented in figure 5 for a mineral and a muck soil. This is the one factor that must be watched in connection with the successful operation of the New York pasteurizer.

In the Ohio, or direct-heating, type of pasteurizer, the moisture factor is also important, but for a different reason; electrical rather than thermal conductivity is the principle involved. A direct measure of this conductivity was obtained with a watt meter which indicated the demand in kilowatts. This demand was found to vary widely with the kind of soil, its moisture, temperature, and the soluble-salt content. The soluble salt varied with the kind of soil; the content was low for pure sand and high for organic soils. The relation of soil moisture and temperature to demand in fine sandy loam with a total waterholding capacity of approximately 50 per cent is illustrated in the left half of figure 6. It may be seen that the cur-

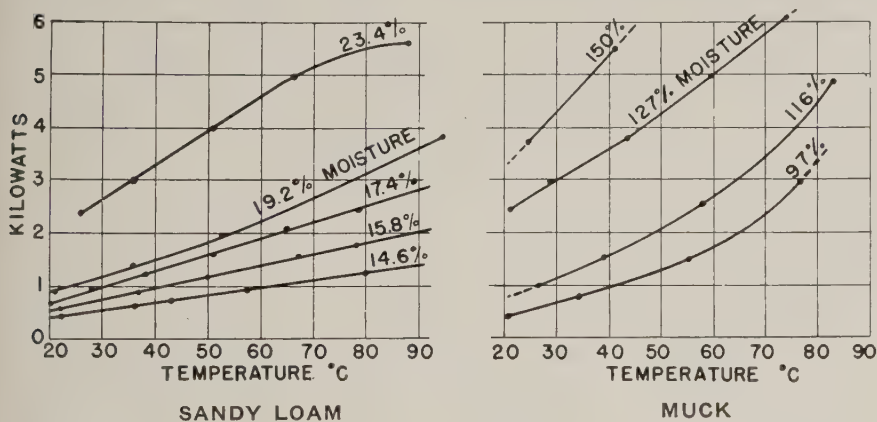


FIGURE 6. EFFECT OF SOIL MOISTURE UPON THE KILOWATT DEMAND AND THE TEMPERATURE RISE, IN THE OHIO (DIRECT-HEATING) TYPE OF PASTEURIZER, FOR TWO KINDS OF SOIL

The current required increases with increase in both the moisture content and the temperature of the soil

rent demand increases with added increments of moisture and also with a rise in temperature. Similar relations hold for a muck soil, as may be seen in the right half of the figure. From this temperature-demand relationship it is evident that an electrolytic conductor or the soil solution is what is carrying the current.

The importance of the moisture factor, when the Ohio pasteurizer is used, can be illustrated in another way by plotting initial moistures against the time required to elevate the temperature of the soil to 70°C., as shown in figure 7. It may readily be seen that the time factor can be cut in half

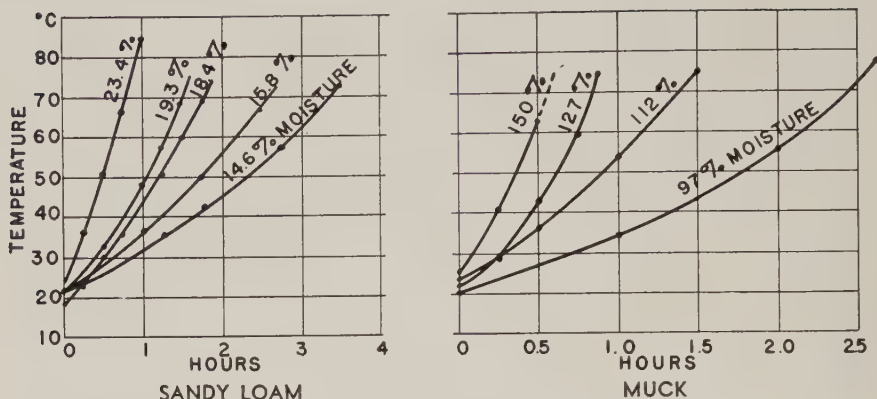


FIGURE 7. EFFECT OF VARYING SOIL MOISTURE UPON THE TIME REQUIRED TO ELEVATE THE TEMPERATURE OF A SOIL TO APPROXIMATELY 70°C. IN THE OHIO (DIRECT-HEATING) TYPE OF PASTEURIZER

Increasing the moisture content greatly shortens the elapsed time. In general, muck soils with their higher nitrate content require less time than do most mineral soils

by a relatively small increase in the initial soil moisture. This holds for both sandy loam and muck soils. In both, the individual test runs with the highest soil moistures (i.e., 23.2 per cent and 150 per cent) were accompanied by the dripping of a slight amount of free water from the pasteurizer during the operation. No attempt, therefore, was made to start with higher initial moisture. From special conductivity studies, however, it was concluded that even these soil moistures were not sufficient to give maximum electrical conductivity.

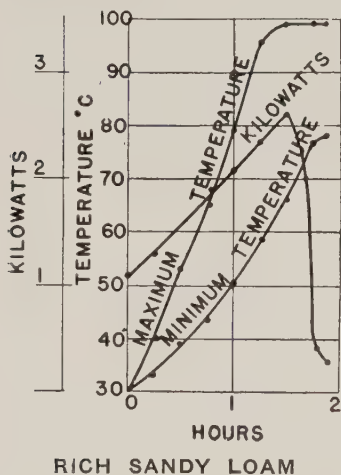


FIGURE 8. EFFECT OF SOIL TEMPERATURE UPON THE KILOWATT-DEMAND CURVE IN THE OHIO (DIRECT-HEATING) TYPE OF PASTEURIZER

When the temperature of the soil at the upper electrode, which is the warmest part of the box, reaches the boiling point, the soil in this region quickly dries out, thus interrupting the flow of current as indicated by the abrupt drop in the kilowatt demand curve. Thus it is not possible to heat soil above 100°C.

AUTOMATIC SAFETY SHUT-OFF FEATURE OF THE OHIO TYPE

Although an inadequate moisture supply may result in a somewhat harmful overheating of a part of the soil in the New York type of pasteurizer, this is impossible in the Ohio type because as soon as the soil steams and dries out, as it does close to the upper electrode on reaching 98°C., good electrical contact is broken and the current is therefore reduced in a very few minutes almost to zero. This has been presented graphically in figure 8, where it may be seen that the peak of the current demand coincides with attainment of the highest soil temperature. But the temperature does not go above the boiling point. When steam begins to escape around the lid it is an indication that the pasteurizer is about to shut itself off.

NECESSITY OF ADDING ELECTROLYTES TO SOME SANDY SOILS

A few samples of cutting-bench sand have been found which had such high resistances that it was necessary to add an electrolyte to obtain a satisfactory temperature rise in a reasonable length of time in the Ohio pasteurizer. This is never necessary with the New York type. In practice, this was accomplished by adding one-twentieth of one per cent of potassium nitrate previously dissolved in enough water to assure even distribution upon shoveling the sand over thoroughly. This amount was found harmless to the growth of cuttings of *Ageratum*, *Coleus*, *Geranium*, and to cucumber seedlings.

An idea of the great variability in electrical resistance of different kinds of soils may be obtained by a glance at table 6. The specific resistances of several supersaturated soil samples were determined with the aid of an electrolytic cell after the manner formerly employed by soil-survey workers in measuring the alkali deposits of the West. Although great accuracy is not claimed for the method, it is sufficiently trustworthy to bring out the wide variation in conductivity of different kinds of soil. These samples were all taken from soils used for the growing of plants, and hence might conceivably need disinfesting at some time. On testing in the Ohio pasteurizer to a depth of 10 inches, it was found that soils with a specific resistance in the neighborhood of 4000 ohms or more required moistening with an electrolyte, as just described, to insure heating within a reasonable number of hours. Reducing the depth of the soil layer was not tried, although it is realized that such a practice might have accomplished a similar result.

TABLE 6. SPECIFIC RESISTANCES OF SEVERAL REPRESENTATIVE SAMPLES OF SOIL USED BY NEW YORK STATE GROWERS

Kind and origin	Specific resistance
	<i>Ohms</i>
1. Muck (old).....	596
2. Muck (old).....	981
3. Muck (new).....	1,033
4. Sandy loam, compost+manure.....	516
5. Sandy loam, potting soil.....	1,433
6. Sandy loam, outdoor pine seedbed.....	1,988
7. Fine sandy loam, field top soil.....	2,324
8. Sandy loam, field top soil, shade-house nursery.....	2,943
9. Sand, not washed, cutting-bench.....	6,280
10. Sand, washed, cutting-bench.....	9,894
11. Sand, coarse, washed, cutting-bench.....	16,305
12. Sand, pure white quartz, cutting-bench.....	27,962
13. Tap water.....	4,792
14. Distilled water.....	24,022

FACTORS AFFECTING THE TEMPERATURE RISE IN DIFFERENT PARTS OF THE SOIL MASS

When a soil contains an excess of moisture, water soon collects in the lower levels and causes a dripping from the bottom of any pasteurizer. Such conditions are accompanied by a lag in the temperature rise of these lower levels. For example, in a sandy soil which dripped even with an initial moisture content of only 10 per cent this lag was found to be as much as 13°C. at the end of an hour's pasteurizing period. A similar lag of 12 to 14 degrees has been detected with a fine sandy loam which dripped

with an initial moisture of 23 per cent. Treatment should be continued until the region of lowest temperature reaches a satisfactory end point.

The corner positions on the Ohio pasteurizer have been known to lag as much as 25°C. behind the center. This tendency can be corrected by carefully pressing or lightly tamping the soil into the corners to increase the continuity of the conductor, or liquid phase, in these regions while leaving the soil loose in other parts of the box. It can also be overcome partially by blocking off the corners with large-sized "V" molding or by eliminating corners entirely through the use of a circular box similar to the half-barrel shown in figure 2.

Care must be exercised to obtain intimate contact between the soil and the electrodes in the Ohio pasteurizer if a uniform temperature rise is to be obtained. This was accomplished in two ways: by moistening the electrodes with a damp cloth or sponge, and by placing heavy weights on the lid. Tests with different weights indicated that $\frac{1}{2}$ pound per square inch was satisfactory. Additional weight even up to $1\frac{1}{2}$ pounds gave slight additional benefit.

Covering the New York pasteurizers with a half-inch layer of a standard brand of insulating board was found beneficial in checking radiation, thereby bringing about more uniform temperature conditions throughout the soil mass. Without insulation there was a tendency for the corner temperatures to lag several degrees behind the average after the current was turned on and for them to decrease fully as rapidly as the rest of the mass when the current was turned off. Although insulation did not save more than five per cent in energy consumption, it was a distinct aid to better disinfection in the corners and would be most useful when it is desired to leave the soil in the pasteurizer for several hours after turning off the current, as in overnight pasteurizing at low temperatures.

In most of the work at this Station the temperature of the soil at the beginning of each test run was very close to room temperature, or 20°C. The figures on the current required to effect disinfection are based on this initial soil temperature. It is quite likely, however, that one may have a cold cutting-bench sand or may desire to disinfest soil from out of doors which may be considerably below 20°C. in early spring. In table 7 is indicated the amount of electricity required to heat sandy loam and muck soils through several different temperature ranges.

To estimate the time, in hours, which is required to treat any given soil in a New York type pasteurizer, it is only necessary to multiply the kilowatt hours required to raise a cubic foot of that soil through a certain temperature range, by the volume of the box in cubic feet, and to divide by the kilowatt capacity of the heaters. This is illustrated in the following formula and example:

$$\text{Time (in hours)} = \frac{\text{Kilowatt hours per cubic foot (table 7)} \times \text{volume of box}}{\text{Kilowatt capacity of heaters}}$$

Example: Estimate the time required to heat a 5-cubic-foot pasteurizer of sandy loam from 10° to 70°C., when the total capacity of the heaters is 1600 watts. Referring to table 7, it is apparent that 1 cubic foot requires 1.44 kilowatt hours to be heated from 10°C. to 70°C.

$$\text{Time} = \frac{1.44 \times 5}{1.6} = \frac{7.2}{1.6} = 4.5 \text{ hours}$$

Four hours and thirty minutes required.

TABLE 7. APPROXIMATE KILOWATT HOURS REQUIRED TO ELEVATE 1 CUBIC FOOT OF SOIL THROUGH CERTAIN TEMPERATURE RANGES*

Initial soil temperature in degrees centigrade	Desired final temperature in degrees centigrade					
	50	55	60	65	70	75
Sandy loam soil						
5.....	1.08	1.20	1.32	1.44	1.56	1.68
10.....	0.96	1.08	1.20	1.32	1.44	1.56
15.....	0.84	0.96	1.08	1.20	1.32	1.44
20.....	0.72	0.84	0.96	1.08	1.20	1.32
25.....	0.60	0.72	0.84	0.96	1.08	1.20
Muck soil						
5.....	1.26	1.40	1.54	1.68	1.82	1.96
10.....	1.12	1.26	1.40	1.54	1.68	1.82
15.....	0.98	1.12	1.26	1.40	1.54	1.68
20.....	0.84	0.98	1.12	1.26	1.40	1.54
25.....	0.70	0.84	0.98	1.12	1.26	1.40

* Based on the mean consumption of 24 watts per degree rise per cubic foot in the sandy loam and 28 watts in the muck (see table 5).

A variation in kind of soil or in its moisture content affects this result somewhat since it affects the amount of electricity required. An increase in moisture lengthens the time, whereas a decrease shortens the time. Conversely, a greater wattage in heater capacity shortens the time and a lower wattage lengthens it. A few trials will enable any operator to determine the approximate time required to treat his soil.

DISINFESTING SOIL IN BENCHES AND IN GROUND BEDS

A number of unsuccessful attempts were made to disinfest soils without removal from the beds, by the use of a standard brand of soil-heating cable. In 1934 no cable on the market was designed to develop the high temperatures required for soil disinfestation. To avoid melting the lead sheath it was necessary to use excessive quantities of the cable per unit volume of soil to obtain sufficient wattage for practical disinfestation.

A series of vertical electrodes spaced from 4 to 8 inches apart, and extending across a bench, have been tested by several workers, using 230 volt current (Anonymous, 1934; Krewatch and Kable, 1933; Scott, 1932; Tavernetti, 1935). The difficulties of maintaining good plate-to-soil contacts in the absence of heavy weights, the very considerable danger confronting the operator, the uneven temperatures obtained, and the power leakage to the ground, all render this method less attractive at the present time. More promise seems to lie in the use of special portable heating units for benches and ground beds; these are, however, still in the experimental stage.

DISCUSSION

The electric method, in general, has the same outstanding advantage possessed by steam. It is universally effective against all pests. At the same time, because of the lower temperatures employed, it is not so likely to leave the soil temporarily in a less productive condition, as does steam under pressure. It does not leave the soil in a puddled condition, as certain chemical and hot-water treatments so often do. Electrical equipment

and energy are available for many growers at a lower initial cost than is adequate steam or hot-water equipment. For the man who already has steam equipment, the electric method may not be economical. Electric pasteurization is cheaper than the dry-formaldehyde method of Wilson and Tilford (1933) but not so economical as the liquid-formaldehyde method of Guterman and Massey (1934), designed to control damping-off.

So far the method is best suited to use where comparatively small quantities of soil are treated at a time as for cutting beds, potting benches, or seedling flats, particularly where nematodes, sclerotial fungi, weeds, and damping-off organisms are present. The largest-sized New York type pasteurizers at present hold 1 cubic yard, operate on 230-volt circuits, and have a fixed demand not exceeding 6 or 7 kilowatts; the Ohio type is limited in size or shape because of its high and variable demand.

The Ohio box is somewhat cheaper to build, and usually has a little shorter operating time, but it has an element of personal hazard connected with its operation. The materials for the Cornell pasteurizer with its 2.4-cubic-foot capacity cost approximately \$17, whereas the New York box with twice the capacity cost \$27. It has been reported to the authors that an Ohio box with twice the capacity of the Cornell box has been built for the same cost. The heating elements for a New-York-type box of one-half yard (13 cubic feet) capacity are now on the market, with directions for building the box and installing them.⁷ Also, a completed box of 1-yard capacity is being marketed.⁸ No one, so far as it is known, is manufacturing the Ohio type of box.

It is suggested that growers who contemplate purchasing or making soil-pasteurizing equipment for their own use consult with representatives of their local electric power companies to determine whether their existing service line can take care of the additional load.

SUMMARY

Two types of portable electric soil "sterilizers", or pasteurizers, are described and compared in certain respects. One employs the soil-resistance principle in which the current passes directly through the soil (Ohio type). The other employs the heating-element principle in which the current passes through resistance heating units properly spaced to impart their heat to the soil by thermal conductance (New York type).

Both types were found capable of destroying a number of common pathogenes, including bacteria; sclerotial fungi, nematodes, and weed seeds.

Evidence is presented to show that it is not necessary to raise soil temperatures above 70°C. in the presence of adequate soil moisture, to kill several common soil pathogenes. All kinds of soils from pure sand to pure muck were effectively treated in both types of pasteurizer. However, in the direct-heating or resistance type (Ohio) it was often necessary to add some dilute electrolyte solution to sand to insure heating in a reasonable time.

In comparison with other standard methods of soil or seed treatment for damping-off control, electric pasteurization appeared to be equal to the best.

⁷ General Electric Company of Schenectady, New York.

⁸ The Consolidated Car Heating Co. of Albany, New York.

The current consumed per cubic foot per degree rise varied with different kinds of soil (22 or 23 watts for a pure sand with its comparatively low water content, and 27 or 28 for muck with its comparatively high water content). In general, a 50-degree-centigrade rise in temperature (from initial 20° to final 70°) required from 1.0 to 1.3 kilowatt hours. Where only nematodes and damping-off organisms are being combated, lower final temperatures are permissible, at a saving of current, if more time is employed.

A certain minimum initial-soil-moisture content was found to be very important for most effective operation of both types of pasteurizer.

Factors affecting the uniform temperature rise in different parts of the soil mass included uniform distribution of soil moisture, position in the box, degree of packing, insulation, intimacy of contact with electrodes, and speed, or time.

Each type of pasteurizer has its distinct advantages and disadvantages, the sum total of which perhaps favor the New York type for general use by the average operator, because of its greater safety and simpler operation.

So far, attempts to disinfest benches and ground beds with ordinary soil-heating cable have not been successful.

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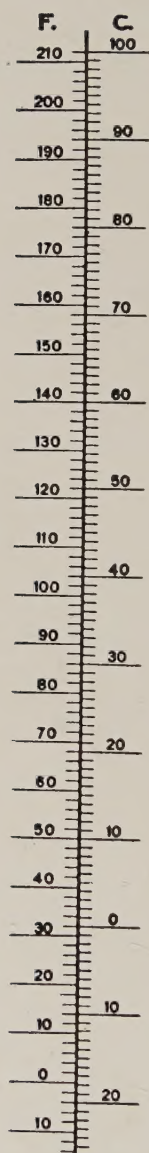


FIGURE 9. FAHRENHEIT-CENTRIGRADE CONVERSION SCALE